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FIELD EVALUATION OF TWO LIQUID ADHESIVES AND AN ENCAPSULATING MATERIAL FOR SECURING TRANSMISSION TOWER ANCHOR BOLT NUTS

Report No. 91-100-K

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ABSTRACT

A field evaluation of two liquid adhesives and an encapsulating material to secure transmission tower anchor bolt nuts was conducted. These materials are being considered to secure tower anchor bolt nuts, so as to limit or prevent unauthorized removal of, or access to, the nuts. The evaluation was conducted by applying the adhesives to, or encapsulating, a series of bolt nuts (November 20, 1990) on three transmission towers, and returning (April 30, 1991) to test the performance of the materials.

The test results were very good. Both the liquid adhesives and the encapsulating material performed as well as, and in some cases better than, previous laboratory tests. There were no observed deficiencies (in performance), which would alter earlier recommendations that these materials be considered as potential solutions for limiting access to transmission tower anchor bolts.

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To

To: Mr. H. Dey
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FIELD EVALUATION OF TWO LIQUID ADHESIVES AND AN ENCAPSULATING MATERIAL FOR SECURING TRANSMISSION TOWER ANCHOR BOLT NUTS

1.0 INTRODUCTION

Following a laboratory evaluation and development of two liquid adhesives/1, 2/ and an encapsulating material for securing transmission tower anchor bolt nuts/3/, a field evaluation was conducted. These products are being considered to secure tower anchor bolt nuts, so as to limit or prevent unauthorized removal of, or access to, the nuts. The use of liquid adhesives is most suitable during construction of the towers. Bolt encapsulation, which involves literally burying the exposed portion of the anchor bolt in a rapid setting material, is being considered for securing nuts on existing towers.

The materials were tested, by securing a series of foundation and tower bolt nuts on three transmission towers. These towers are part of the second 500 kV Lennox to Hawthorne line and are located near Smiths Falls, Ontario. They are identified as tower numbers 522-south to 524-south. The materials were applied on November 20, 1990, and their performance was evaluated on April 30, 1991. The purpose of this report is to present complete details (for permanent record) of the original installation work and the test results.

2.0 PRODUCTS TESTED

2.1 Liquid Adhesives

1. Capbond HS - Rapid (Capbond)

This adhesive is based on an epoxy resin, whose recommended ambient temperature range of use is 5° to 30°C. It is further recommended, when using this material at ambient temperatures below 10°C, that the epoxy (but not necessarily the steel bolting hardware) be preheated. The optimum temperature range of this resin, prior to use, is between 15° and 20°C. For these trials, Capbond was available in pre-proportioned, self-contained units (ie, Semkits) of 168 mL (6 oz) and 280 mL (10 oz) (see Figure 1a).

2. VLT Bolt Adhesive #3 (VLT)

This adhesive is based on a vinyl-ester resin that is catalyzed with 50% active benzoyl peroxide (BPO) powder. The recommended ambient temperature range of use for VLT is -15° to +5°C. No preheating of the resin and steel bolting hardware is necessary. For these trials, VLT was available in one-litre quantities of resin and 45 g units of BPO (see Figure 1b). Future availability will be in 150 mL pre-proportioned, self-contained packages.

Note: For both adhesives, the bolting hardware (ie, nut, bolt and washer) should be dry and free from any surface contamination such as dirt, oil, grease, etc.

2.2 Encapsulating Material

1. Caphard BCE (BCE)

This product is based on an epoxy resin, whose recommended ambient temperature range of use is 5° to 30°C. It is further recommended, when using this material at ambient temperatures below 10°C, that the resin (but not necessarily the aggregate and/or the steel bolting hardware) be preheated. The optimum temperature range of this resin, prior to use, is between 20° and 25°C. BCE resin is available in 4.1 L quantities (ie, Component A = 3.25 L and Component B = 0.85 L). Up to 20 kg of graded aggregate (maximum size 10 mm) is to be blended with the resin.

3.0 APPLICATION OF THE MATERIALS

The initial application of the liquid adhesives and the encapsulating material was conducted on November 20, 1990. The day was overcast, but with no precipitation. The ambient temperature ranged between 5°C at 8:00 am and 7°C at 3:00 pm. The work conducted is described below (see also Table 1).

3.1 Tower 524 South (Z11S-A)

Capbond HS - Rapid was used to secure all the foundation bolt nuts and some selected tower bolt nuts on this tower. The ambient temperature during application was 5°C. The temperature of the units of Capbond was approximately 15°C, and they were kept warm by leaving them in the cab of the truck. The steel bolting hardware was not preheated.

Additional details and observations are given below.

1. Foundation Bolts

(a) All eight 35 mm (1-3/8 in) diameter foundation bolts (ie, 2 bolts per leg) were secured (See Figure 2).

(b) Prior to applying the adhesive, excess tar, which was on the anchor bolt, nut and washer, was removed. The bolts, nuts and washers were cleansed with a solution of methyl ethyl ketone (50%) and xylol (50%). A wire brush was also used to scrub the bolts (see Figure 3).

(c) One complete 280 mL (10 oz) unit of Capbond was required to treat all eight bolts. The adhesive was first mixed in the self-contained plastic cartridge (see Figure 1a) and dispensed into a larger container to facilitate application (Figure 4a). Material was brushed on the exposed threads of the anchor bolt, as well as on the threads on the inside of the nut (Figure 4b).

(d) All nuts were torqued to 405 N•m (300 ft•lb) after application of the adhesive.

(e) Extra adhesive was applied to the exposed bolt threads, above the nut, after torquing. Approximately, half of a 280 mL (6 oz) unit was used for this procedure.

2. Tower Bolts

(a) A total of eight 16 mm (5/8 in) diameter tower bolts were secured. The location of these bolts is described as being "the bottom-most bolt, on the first splice, on the parallel and normal faces, of legs 1 to 4" (see Figure 5).

(b) No special surface preparation of these bolts, nuts and washers was necessary.

(c) Approximately, half of a 280 mL (6 oz) unit was used to treat these eight bolts. Similar to the foundation bolts, Capbond was first mixed in the self-contained cartridge. Once mixed, the adhesive was dispensed into a larger container to facilitate brushing the adhesive on the threads of the bolt, and on the inside of the nut.

(d) All nuts were torqued to 120 N•m (90 ft•lb) after application of the adhesive.

(e) Extra adhesive was applied to the exposed bolt threads, above the nut, after torquing. Approximately, one-third of a 280 mL (6 oz) unit was used for this procedure.

3.2 Tower 523 South (Z11-LM)

Caphard BCE was used to encapsulate a total of ten (of a possible sixteen), 51 mm (2 in) diameter foundation bolts on this tower (see Figure 6). The ambient temperature during application was 6°C. The temperature of the resin was approximately 16°C, and it was kept warm by leaving it in the cab of the truck. The aggregate and steel bolting hardware were not preheated, and no other special surface preparation (ie, cleansing, scrubbing, etc) of these bolts was necessary.

Before mixing BCE, 140 mm (5-1/2 in) diameter Sonotube forms were first set up around each bolt (see Figure 7a). The Sonotube was held in place with silicone caulking that had been preheated to 18°C. Unless otherwise noted, all the Sonotube forms were cut to a height of 127 mm.

The material was proportioned according to manufacturer's instructions, that is, one batch consisted of 3.25 L of Component A (resin), 0.85 L of Component B (catalyst) and up to 20 kg of graded aggregate (maximum size 10 mm). All components were blended in a 20-L plastic pail with the use of a jiffler-type mixer powered by a hand-held drill. Note that at this relatively low ambient temperature, only 12.5 kg of aggregate was used for each batch in order to maintain a workable mix. A total of two batches were required to encapsulate all ten bolts. The blended BCE was placed into the formwork (see Figure 7b) and no special placing or finishing procedures were required.

Additional details and observations are as follows:

1. On leg 1, three (of the possible four) foundation nuts were encapsulated. Two of the nuts were clear of the diagonal tower members (normal and parallel sides) that framed into the lower portion of the shoe footing. The third nut could not be removed unless the diagonal tower member on the normal side was first removed (see Figure 6). In fact, for this latter nut, the flange of the diagonal member interfered with the top of the Sonotube form. To accommodate the flange, a diagonal cut was made in the Sonotube (see Figure 8a).

2. On leg 2, similar to leg 1, three (of the possible four) foundation nuts were encapsulated, and two of the nuts were clear of the diagonal tower members (normal and parallel sides) that framed into the lower portion of the shoe footing. The third nut could not be removed unless the diagonal tower member on the parallel side was first removed (see Figure 6). To accommodate the flange, in this instance, the Sonotube form was cut to a height of 75 mm (see Figure 8b).

3. On legs 3 and 4, only two nuts were encapsulated. These nuts are described as the ones which were clear of the diagonal tower members that framed into the lower portion of the shoe footing (see Figures 6 and 7a).

3.3 Tower 522 South (Z11S-A)

VLT Bolt Adhesive #3 was used to secure all the foundation bolts, nuts and some selected tower bolt nuts on this tower. The ambient temperature during application was 7°C. The temperature of VLT was also 7°C, and the steel bolting hardware was not preheated.

All work that was completed on this tower (ie, surface preparation, bolt locations, etc) was the same as for Tower 524-south. Therefore, refer to Section 3.1 and Figures 1 to 5.

One additional comment on this product is as follows:

As previously indicated, the VLT resin was available in one-litre containers (see Figure 1b). Hence, the BPO catalyst was simply added to the resin and mixed directly in the one-litre container. However, due to the ambient temperature (7°C), the elapsed time before this relatively large quantity of material had gelled and was unworkable, was only approximately 12 minutes. Therefore, separate, one litre quantities of VLT had to be mixed, to first secure the eight, 35 mm (1-3/8 in) diameter foundation bolts followed by the eight, 16 mm (5/8 in) diameter tower bolts. In each case, the work had to be completed quickly (ie, less than 12 minutes), and in both cases, approximately 600-750 mL of material was wasted. Future availability for this product will be 150 mL pre-proportioned, self-contained packages.

4.0 RESULTS AND DISCUSSION

4.1 Liquid Adhesives - Capbond HS - Rapid and VLT Bolt Adhesive #3

4.1.1 Foundation Bolts

The results of the torque tests conducted on the 35 mm (1-3/8 in) diameter foundation bolts, (see Figure 9a), secured with each liquid adhesive, are given in Table 2. These values were obtained by averaging the results for seven bolts that had been secured with Capbond and six bolts that had been secured with VLT. (The additional foundation bolts that had been secured with Capbond (one bolt) and VLT (two bolts) were tested by preheating them with a propane torch. These results have not been included in the averages given in Table 2 and are discussed later). Also provided in Table 2, for comparison purposes, are the expected breaking torques for the 35 mm (1-1/8) diameter bolts, based on previous laboratory results/2/. Also note that two expected breaking torques are reported for each adhesive, because it was found that the ambient temperature during application and curing was found to be an important variable. In the laboratory, Capbond had been applied and cured at a constant temperature of 22° or 0°C, and the corresponding temperatures for VLT were 22° or -15°C. In the field, the application temperature was 5° and 7°C for Capbond and VLT, respectively, and the curing temperatures and conditions were much more variable (ie, daily temperature fluctuations accompanied by rain and snow during the 5-month period between November 20, 1990, and April 30, 1991). However, the average breaking torques in the field were all in excess of 1355 N•m (1000 ft•lb), regardless of adhesive, and all fell within the range of expected results (defined by the laboratory application/curing temperatures) for each adhesive. One final comment regarding Table 2 is that expected prevailing torque values are not reported. These values are

not reported because the laboratory results were far more inconsistent and also much lower than the results obtained from the field tests.

Three additional foundation bolts (ie, one secured with Capbond and two secured with VLT) were also tested. These tests were conducted by preheating the nut/washer assembly for a period of 5 minutes with a small propane torch and were meant to evaluate the effect of high temperature on torque resistance. The results have not been included in Table 2 and are reported as follows:

For Capbond HS - Rapid

- the breaking torque was 405 N•m (300 ft•lb) and the prevailing torque was 375 N•m (275 ft•lb).
- when this nut was retested some 30 minutes later (ie, after cooling to ambient temperature), the prevailing torque was 1085 N•m (800 ft•lb) (as compared to 1385 N•m (1020 ft•lb) for unheated bolts).

For VLT Bolt Adhesive #3

- for one bolt, the breaking torque as well as the prevailing torques was 1765 N•m (1300 ft•lb).
- for the second bolt, the breaking torque was 1085 N•m (800 ft•lb) and the prevailing torque was 950 N•m (700 ft•lb).
- when the second nut was retested some 30 minutes later (ie, after cooling to ambient temperature), the prevailing torque was 1560 N•m (1150 ft•lb) (as compared to 1625 N•m (1200 ft•lb) for unheated bolts).

Additional subjective comments/observations from the foundation bolt tests are as follows:

1. One person, using a torque wrench with a 1.85 m (6 ft) lever arm, could not generate enough torque to break the bond on 12 of 13 (ie, non-preheated) foundation bolts, regardless of which bolt adhesive was used. The breaking torque of these bolts was 1355 N•m (1000 ft•lb) or greater (see Table 2), and required two people using the 1.85 m (6 ft) long wrench.

2. The lowest breaking torque was 1765 N•m (700 ft•lb), and this was obtained for a bolt treated with VLT Bolt Adhesive #3. In this case, one person using the 1.85 m (6 ft) long wrench was able to break the bond.

3. Additional factors contributing to the difficulty in untorquing the foundation bolts were the awkward position one had to be in to pull on the wrench (ie, bent over in a semi-squatting position) and the poor footing (ie, uneven and on loose rock and stone).

4. The torque required to turn each nut an additional 1/2 turn after breaking (ie, prevailing torque) averaged greater than 1355 N•m (1000 ft•lb), regardless of the adhesive used (see Table 2). However, to turn each nut further (ie, an additional one or two turns), the required torque, in most cases, was as high as or, in some cases, greater than the prevailing torques reported in Table 2. It was extremely difficult for one person using the 1.85 m (6 ft) long wrench to overcome all prevailing torques (except for the nut which loosened (ie, bond broke) at 950 N•m (700 ft•lb)). If a 0.9 m (3 ft) long wrench was used, it was virtually impossible for one person to overcome the prevailing torques.

5. The prevailing torques obtained in the field were much more consistent and always greater than those obtained in previous laboratory tests/2/. The reason for this is probably due to being able to apply a continuous high level of torque with a pneumatic torque multiplying tool (in the laboratory) after breaking. The frictional heat developed, while the nut was continuously turned, contributed to the variable and, in general, low prevailing torques obtained in the laboratory. In the field, the maximum travel of the nut was only 1/2 turn before the position of the wrench had to be reset. Also, more often than not, the persons torquing the nut had to pause and rest between each application of force.

4.1.2 Tower Bolts

The results of torque tests conducted on the 16 mm (5/8 in) diameter tower bolts (see Figure 9b), secured with each bolt adhesive, are given in Table 3. These values were obtained by averaging the results for six bolts that had been secured with Capbond and all eight bolts that had been secured with VLT. (Two additional bolts, secured with Capbond, were tested by preheating them with a propane torch. These results have not been included in the averages given in Table 3 and are discussed later). Also given in Table 3 are the expected breaking torque values for the 16 mm (5/8 in) diameter tower bolts (see also Section 4.1(a)). As seen, the breaking torques for the bolts secured with VLT averaged 265 N•m (195 ft•lb) and thus fell within the range of predicted values (ie, 205 to 340 N•m (150 to 250 ft•lb). The Capbond field result, while also averaging approximately 265 N•m (195 ft•lb), was lower (by approximately 20%) than the lowest predicted value.

Two additional tower bolts, secured with Capbond, were tested. These tests were conducted by using a 305 mm (12 in) long "conventional" wrench rather than a 455 mm (18 in) long torque wrench. The results of these tests have not been included in Table 3 and are reported as follows:

- the first nut could not be loosened with one man using a 305 mm (12 in) long "conventional" wrench. The bond was broken by striking the end of the wrench with a rock several times, thus applying a "shock" load to the nut.

- similarly, the second nut could not be loosened with one man using a 305 mm (12 in) long "conventional" wrench. To remove this nut, the bolt and nut were heated with a small propane torch for a few minutes, after which, the nut was easily loosened.

Additional subjective comments/observations from the tower bolt tests are as follows:

1. Once the initial bond was broken (ie, by use of the 455 mm (18 in) long torque wrench, striking a 305 mm (12 in) long "conventional" wrench with a heavy object or heating the nut/bolt before applying torque), the use of a second wrench was always necessary to hold the opposite end of the bolt to prevent it from turning (See Figure 9b). Also, once the bond was broken, it was still very difficult to completely remove the nut when using the 305 mm (12 in) long "conventional" wrench.

2. Some tower bolts/nuts were first repeatedly struck with a hammer, and excess adhesive on the exposed threads of the bolt was chipped away, prior to testing. These efforts did not reduce the breaking torque.

3. A number of tower bolts that had not been secured with an adhesive were tested. These nuts were easily loosened with the use of the 305 mm (12 in) long wrench. To completely remove the nut, it was not necessary to hold the opposite end of the bolt with a second wrench. (Note: These bolts had been initially torqued to 122 N•m (90 ft•lb)).

4.2 Encapsulating Material - Caphard BCE

Two of the 10 nuts that were encapsulated in "blocks" of Caphard BCE were fully exposed (see Figure 6). The various means of breaking/removing the encapsulation blocks and exposing the nuts were as follows:

- repeatedly striking the block with a 6 kg (13.2 lb) sledge hammer (Figure 10).
- using a hacksaw to try and cut through the block.
- using a small propane torch to burn the block (Figure 11a).
- using an electric drill to drill into the block (Figure 11b).
- using a hammer and chisel to either split the material along a plane of weakness caused by sledge hammering/hacksawing/drilling or to chip away charred material after burning.

Various combinations of the above-mentioned techniques were attempted for each block. However, the most successful operation to expose one of the nuts (ie, the second block tested) was to begin by first strategically drilling into the block to create intersecting planes of weakness. Next, the block was repeatedly struck with a sledge hammer in an attempt to further weaken the block. Finally, a chisel was driven into these planes of weakness so as to split off some of the material. It was also found that there was poor adhesion between the epoxy material and the foundation bolt and nut (ie, steel hardware). Therefore, once the bolt and nut were at least partially exposed, the chisel was driven between the epoxy and nut to separate these components. The entire operation to completely expose this particular nut took a minimum of 20 minutes.

Additional subjective comments/observations from the bolt encapsulation tests are as follows:

1. The most success, at removing the encapsulating block, was obtained when using an electric drill. The hacksaw blade was impeded by the stone aggregate and creating planes of weakness with just the use of a sledge hammer or chisel only was very laborious and time-consuming. Thus, if an electric drill had not been available, the 20-minute duration to remove a block would have been substantially longer.

2. An indication of the effectiveness of the bolt encapsulating material is in the level of frustration or difficulty it provides in limiting or discouraging access to a nut. This assessment is very subjective and is something that is not easily conveyed (in words). Therefore, a short, video (VHS format) depicting some of the efforts described above to break open the encapsulation blocks has been prepared. Copies can be obtained by contacting Mr. G.S. Kellay, Supervising Engineer, Concrete Technology Section, Civil Research Department, extension 6682. [Note: Also shown on the video are some of the torque tests that were conducted to assess the liquid adhesives].

5.0 SUMMARY AND RECOMMENDATIONS

The field trials went well. Both liquid adhesives (Capbond HS - Rapid and VLT Bolt Adhesive #3) and the one encapsulating material (Caphard BCE) performed as well as, and in some cases better than, the laboratory tests/2/. For the liquid adhesives, the average breaking torque results from the field tests all generally fell within the range of expected results (based on the previous laboratory tests), and the field prevailing torques were all much more consistent and greater than those obtained in the laboratory. The encapsulating material provided the same (ie, expected) resistance to sledgehammering, chiselling, hacksawing, burning and drilling as had been observed in the laboratory tests. The materials had been originally applied (November 20, 1990) and fully cured (November 20, 1990 to April 30, 1991) under field conditions. There were no observed deficiencies in performance which would alter the earlier recommendations/2,3/ that these materials be considered as potential solutions for limiting unauthorized access to transmission tower foundation bolts. If these products are going to be used on a regular basis for transmission line construction (or maintenance), it is further recommended that a standard Ontario Hydro specification detailing proper handling, installation and safety procedures, etc, should be prepared. Presently, guidance is available in References 2 and 3 (as well as from this report).

[Note: Long-term durability testing of these products has been initiated. Current results, available after 28 days of exposure to 23°, 38° and 50°C environments, do not indicate any deterioration in performance. Exposure to these conditions will continue, and tests also include natural outdoor exposure for durations up to and including 3 years.]

6.0 ACKNOWLEDGEMENTS

The assistance of Messrs. P. St. Denis and C. Adams in organizing the field resources (ie, equipment, etc) for the initial installation work, and the assistance of Mr. J. McLeod on the day of the installation work (November 20, 1990) is gratefully acknowledged. As well, the interest and attendance of Messrs G. Juhn, K. Kong and P. Perry at the initial installation and/or the day of the tests was appreciated.

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3. Sato, J.A. and Deans, J.J., "Evaluation of Bolt Encapsulation Materials for Securing Transmission Tower Anchor Bolt Nuts", Ontario Hydro Research Division, Report No S91-1-K, March 6, 1991, 16 pp.

TABLE 1

SUMMARY OF THE BOLTS THAT WERE SECURED

Product	Tower [1] I.D.	Leg No.	No. of Foundation Bolts Secured [2]	No. of Tower Bolts Secured [3]	No. of Foundation Bolts Secured [4]
Capbond HS-Rapid	524 - South	1	2	2	–
		2	2	2	–
		3	2	2	–
		4	2	2	–
Caphard BCE	523 - South	1	–	–	3
		2	–	–	3
		3	–	–	2
		4	–	–	2
VLT Bolt Adhesive #3	522 - South	1	2	2	–
		2	2	2	–
		3	2	2	–
		4	2	2	–

[1] The towers are part of the second 500 kV Lennox to Hawthorne transmission line, and are located near Smith Falls, Ontario.

[2] These bolts were 35 mm (1 - 3/8 in) diameter (see also Figure 2).

[3] These bolts were 16 mm (5/8 in) diameter (see also Figure 5).

[4] These bolts were 51 mm (2 in) diameter (see also Figure 6).

TABLE 2

RESULTS[1] FROM THE FOUNDATION BOLT[2] TESTS

	Capbond HS - Rapid				VLT Bolt Adhesive #3			
	Breaking Torque	Prevailing[3] Torque	Expected Breaking[4] Torque		Breaking Torque	Prevailing[3] Torque	Expected Breaking[4] Torque	
			22°C	0°C			22°C	-15°C
Range	1355 - 1760 (1000 - 1300)	1085 - 1760 (800 - 1300)	--	--	950 - 1760 (700 - 1300)	810 - 1965 (600 - 1450)	--	--
Average	1625 (1200)	1385 (1020)	1585 (1170)	1830 (1350)	1585 (1170)	1625 (1200)	990 (730)	1695 (1250)
Std. Deviation	165 (120)	215 (160)	--	--	285 (210)	460 (340)	--	--

[1] Torque reported in N.m (ft.lb)

[2] Bolt diameter = 35 mm (1-3/8 in)

[3] Prevailing torque is defined as the torque required to move the nut an additional 1/2 turn (after breaking).

[4] Test values are based on the results from previous laboratory tests, which were conducted at two different application/curing temperatures.

Note:

The nuts were torqued to 405 N.m (300 ft. lb) after application of the adhesive.

TABLE 3

RESULTS[1] FROM THE TOWER BOLT[2] TESTS

	Capbond HS - Rapid				VLT Bolt Adhesive #3			
	Breaking Torque	Prevailing[3] Torque	Expected Breaking[4] Torque		Breaking Torque	Prevailing[3] Torque	Expected Breaking[4] Torque	
			22°C	0°C			22°C	-15°C
Range	235 - 340 (175 - 250)	205 - 270 (150 - 200)	--	--	235 - 290 (175 - 215)	100 - 250 (75 - 185)	--	--
Average	270 (200)	225 (165)	340 (250)	400 (295)	265 (195)	205 (150)	205 (150)	340 (250)
Std. Deviation	40 (28)	40 (28)	--	--	20 (16)	55 (41)	--	--

[1] Torque reported in N.m (ft.lb)

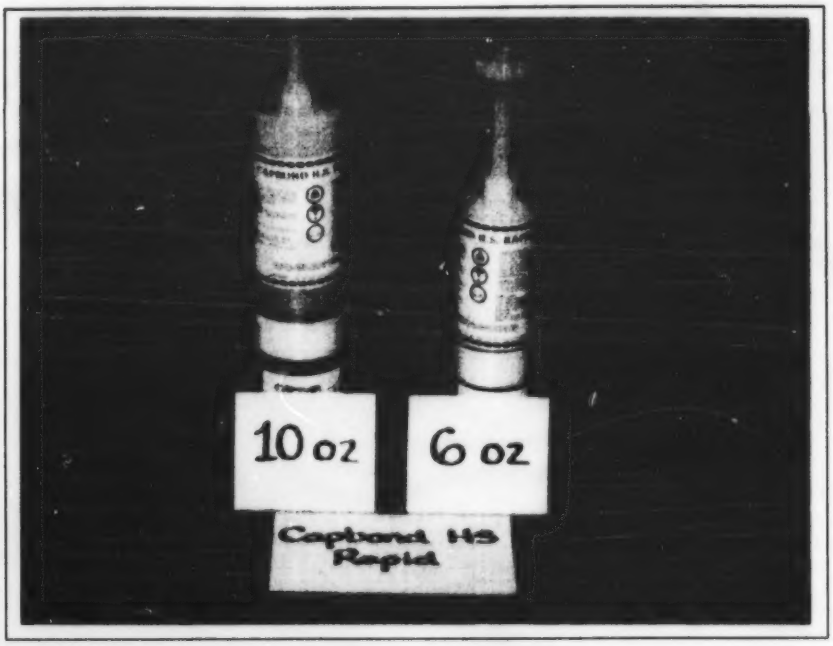
[2] Bolt diameter = 16 mm (5/8 in).

[3] Prevailing torque is defined as the torque required to move the nut an additional 1/2 turn (after breaking).

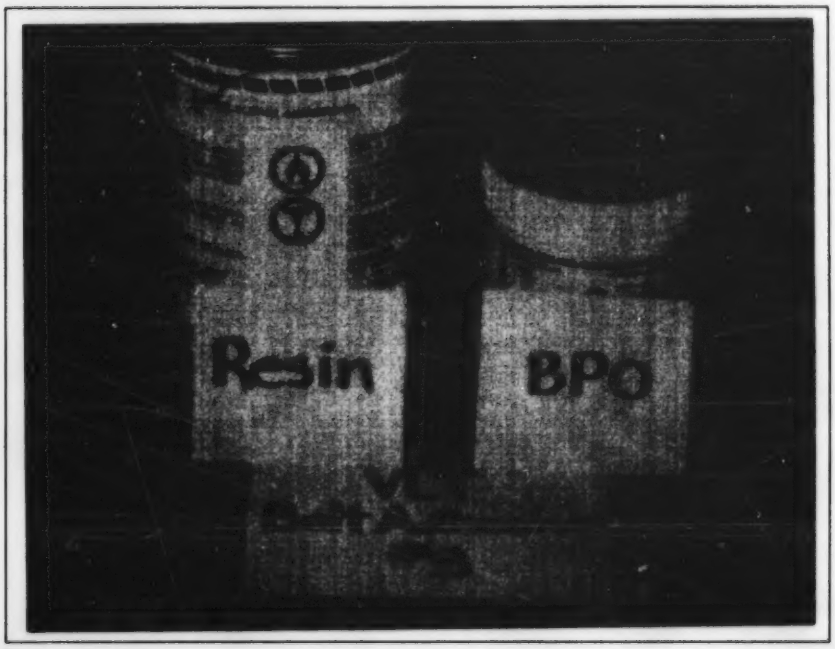
[4] Test values are based on the results from previous laboratory tests, which were conducted at two different application/curing temperatures.

Note:

The nuts were torqued to 120 N.m (90 ft.lb) after application of the adhesive.



a) Capbond HS - Rapid

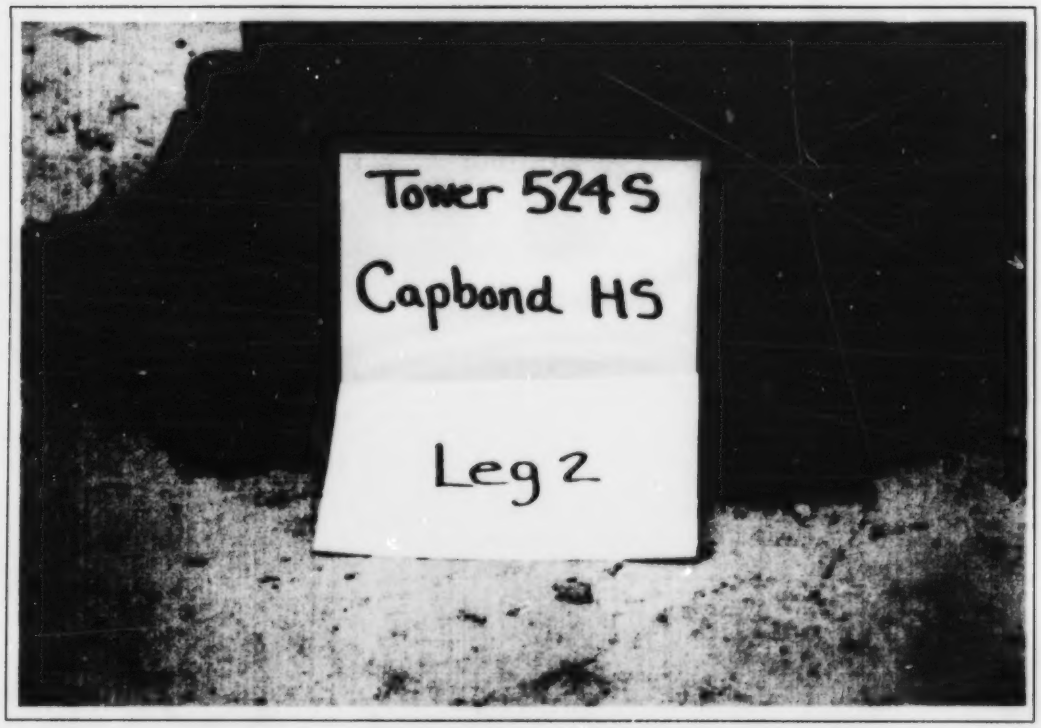


b) VLT Bolt Adhesive #3

FIGURE 1

LIQUID ADHESIVES

91-100
186164-K18-RD



Notes:

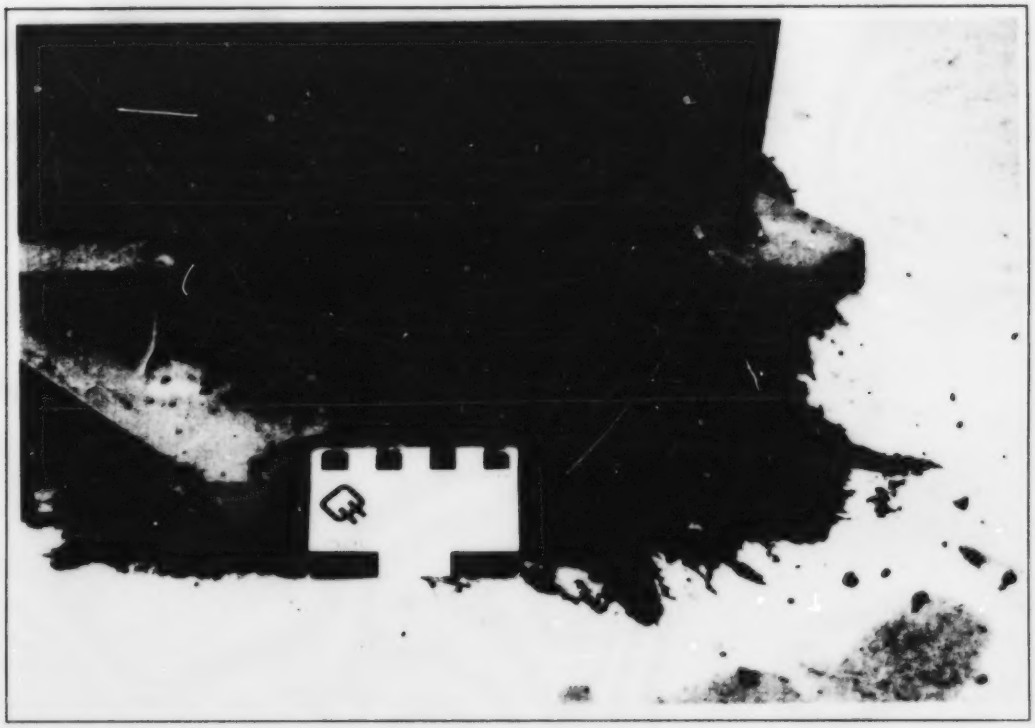
1. The liquid adhesives were used to secure all eight 35 mm ø foundation bolts on each of two Z11S-A towers (Nos. 524-south and 522-south).

2. Actually shown in this figure are the foundation bolts on leg 2 of Tower 524-south. These bolts had been secured with Capbond HS - Rapid.

3. The foundation bolts on Tower 522-south were secured with VLT Bolt Adhesive #3.

FIGURE 2

FOUNDATION BOLTS (35 mm ø) FOR THE LIQUID ADHESIVES



Note:

All foundation bolts for Towers 524-south (Capbond HS - Rapid) and 522-south (VLT Bolts Adhesive #3) had to be cleansed to remove excess tar from the bolt, nut and washer prior to application of the bolt adhesives.

FIGURE 3

TYPICAL FOUNDATION BOLT THAT HAD BEEN CLEANSED PRIOR TO APPLICATION OF A BOLT ADHESIVE

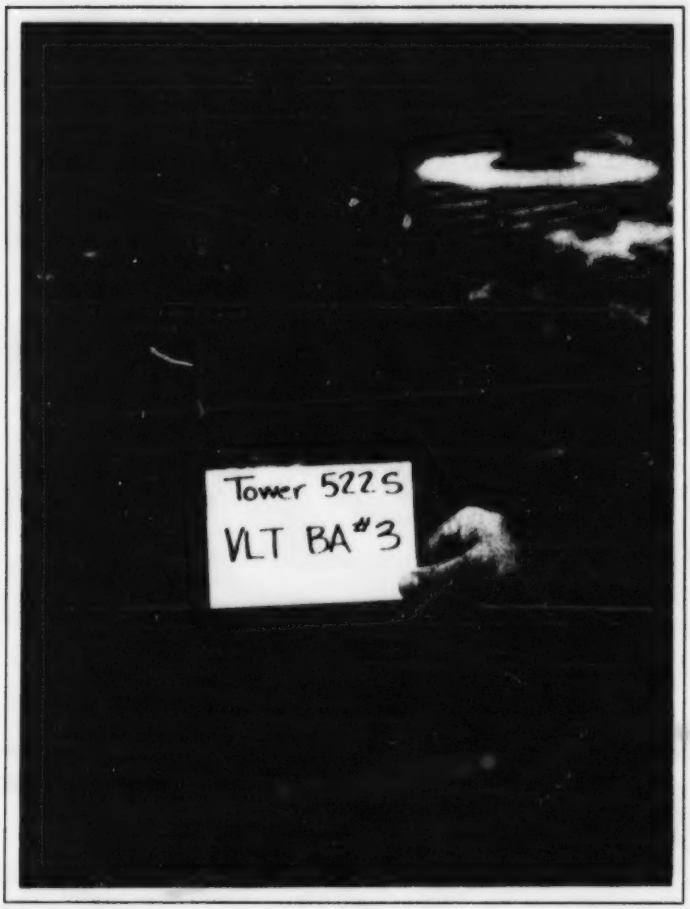
a) Dispensing mixed contents into another container

b) Brushing the adhesive on the nut, bolt, etc.

Note:
The application procedure shown in this figure is generally the same for VLT Bolt Adhesive #3. The resin and BPO are mixed in the one litre cans that the resin is packaged in (see also Figure 1b), and a paint brush is used to apply the adhesive on the nut, bolt, etc.

FIGURE 4

APPLICATION OF CAPBOND HS - RAPID



Notes:

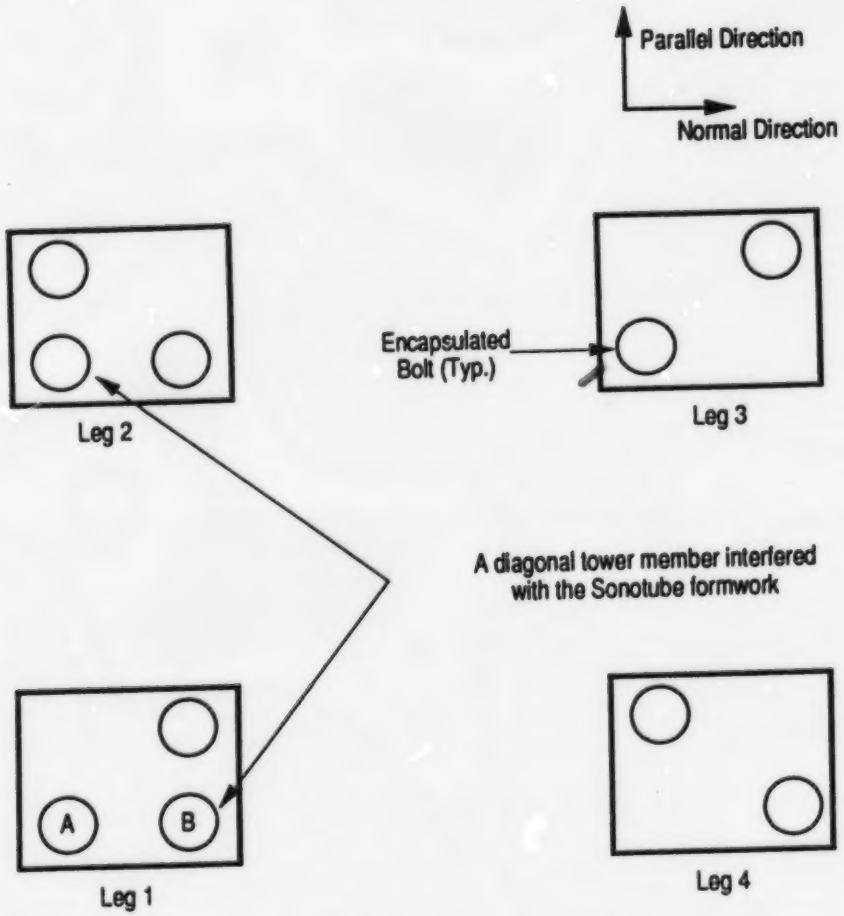
1. The liquid adhesives were used to secure eight selected 16 mm ø tower bolts on each of two Z11S-A towers (Nos. 524-south and 522-south). The bolts are described as being "the bottom-most bolt, on the first splice, on the parallel and normal faces of legs 1 - 4".

2. Actually shown in this figure are the two tower bolts on leg 3 of Tower 522-south. These bolts had been secured with VLT Bolt Adhesive #3.

3. The tower bolts on Tower 524-south were secured with Capbond HS - Rapid.

FIGURE 5

TOWER BOLTS (16 mm ø) FOR THE LIQUID ADHESIVES

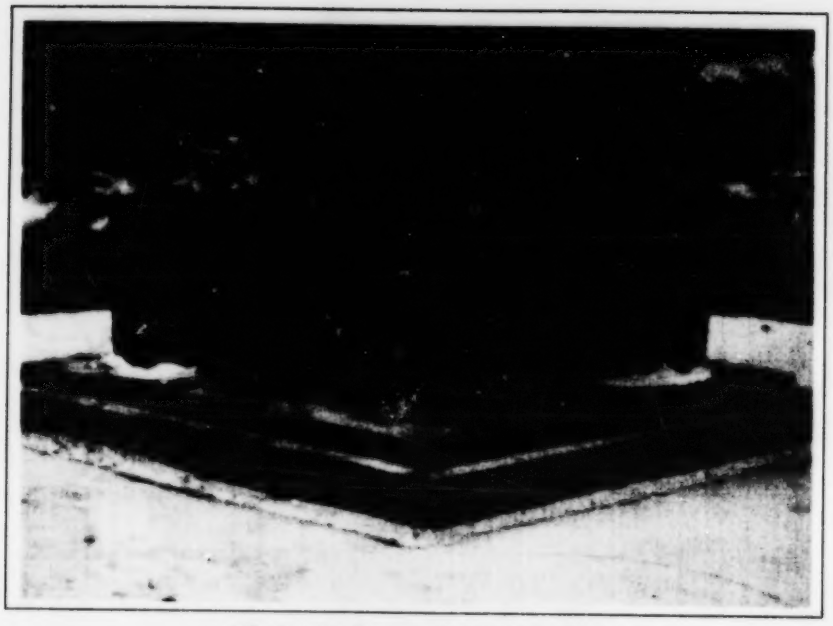


Notes:

1. Plan view of 51 mm (2 in) diameter foundation bolts for Tower 523-south.
2. Unless otherwise noted, all bolts were clear of diagonal tower members that framed into the lower portion of the shoe footing (see also Figures 7 and 8).
3. The encapsulation blocks around the nuts identified as 'A' and 'B' were the only ones tested (ie., broken apart).
4. Not to scale

FIGURE 6

LOCATIONS OF ENCAPSULATED FOUNDATION BOLTS

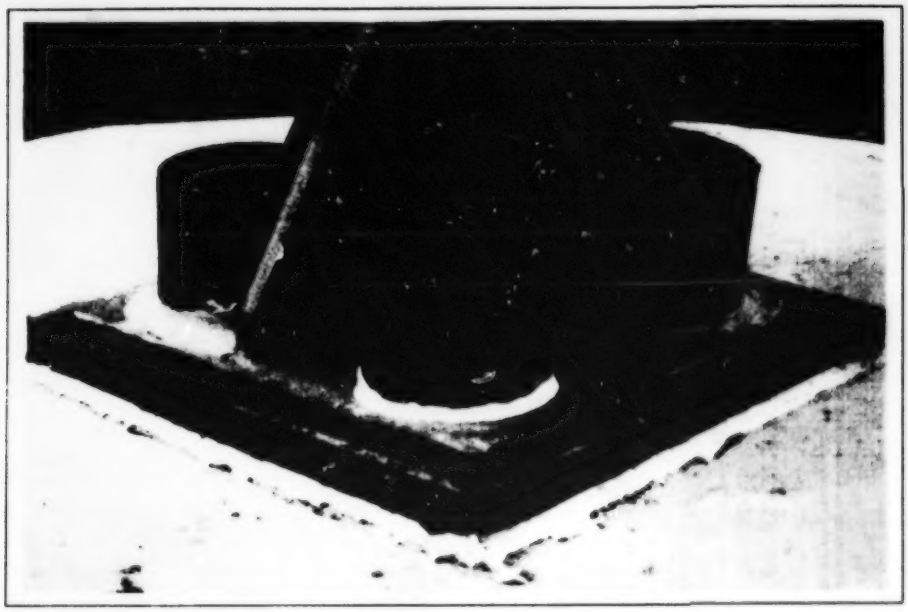


a) Sonotube Formwork in Place (Typ.)

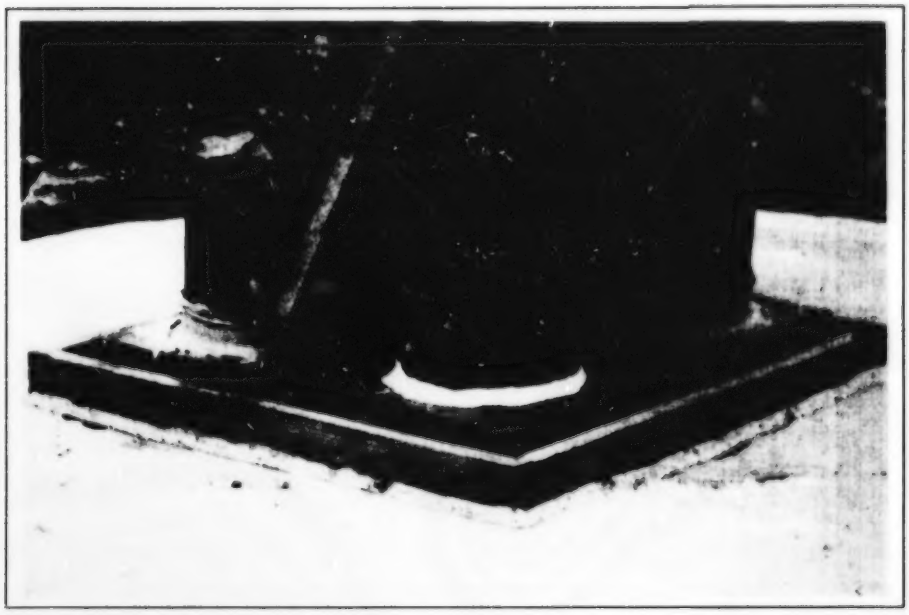
b) Placing Material into Forms

FIGURE 7

PLACING CAPHARD BCE



a) Leg 1 - Sonotube cut to Accommodate Flange

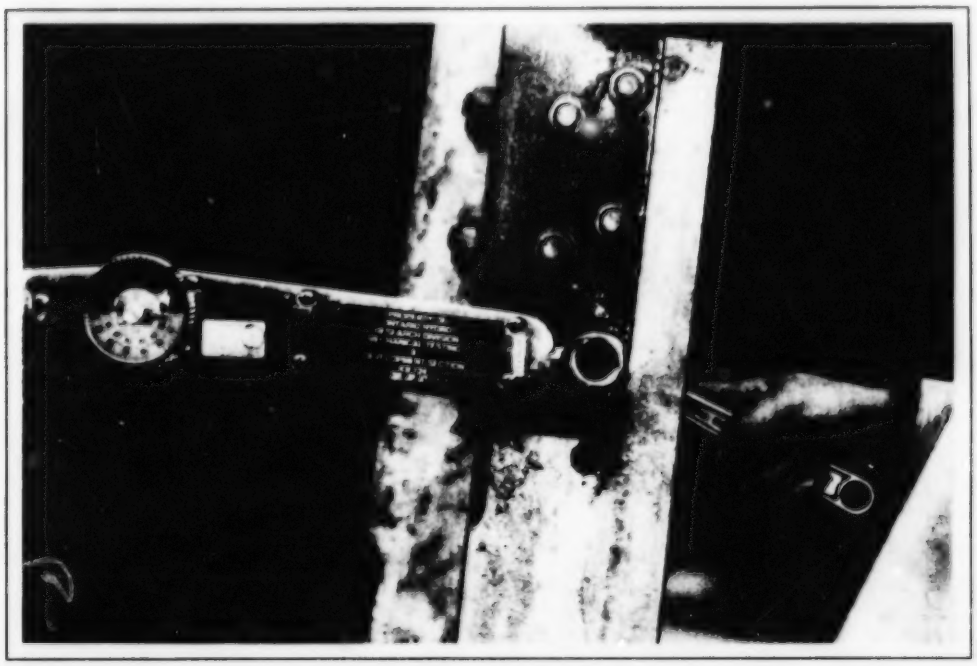


b) Leg 2 - Sonotube cut to a Height of 75 mm to Accommodate Flange

FIGURE 8

SONOTUBE FORMWORK SET UP AROUND SELECTED FOUNDATION BOLTS FOR LEGS 1 AND 2 ON TOWER 523-SOUTH

a) Foundation Bolt Torque Test



b) Tower Bolt Torque Test

FIGURE 9

BOLT TORQUE TESTS

FIGURE 10

SLEDGE HAMMERING THE ENCAPSULATION BLOCK

a) Burning

b) Drilling

FIGURE 11

ADDITIONAL TESTING OF THE ENCAPSULATION BLOCK